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Examining the Influence of Grip Type on Wrist and Club Head Kinematics during the Golf Swing: Benefits of a Local Co-ordinate System

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Abstract

Wrists movements have been identified as an important factor in producing a successful golf swing, with their complex motion influencing both club head velocity and orientation. However, a detailed analysis of wrist angles is lacking in the literature. The purpose of this study was to determine kinematics across wrists and club head characteristics during the golf swing under weak, neutral and strong grip conditions. Twelve professional male golfers executed 24 shots using a driver under three grip conditions. A six degrees of freedom analysis of the hand with respect to the distal forearm was performed using a 10-camera three-dimensional motion capture system. Differences in joint angles were explored using repeated measures ANOVAs at key swing events (onset, top of backswing and impact), in addition club head velocity and clubface angle at impact were also explored. Main findings revealed significant differences in flexion/extension and internal/external rotation for both wrists at all swing events, whereas fewer significant interactions were found in ulnar/radial deviation across grips for both wrists at all events. Clubface angle only differed significantly between the weak and the strong and neural grips, presenting a more ‘open’ clubface to the intended hitting direction. This study is the first to explore tri-planar wrist movement and the effect of different grips, such analysis has implications for coaching knowledge and practice and should inform future research into different aspects of skill, technique analysis and may inform injury mechanisms/prevention.

Keywords: driver, golf, Qualisys, internal/external rotation, range of motion, six degrees of freedom analysis.

Examining the Influence of Different Grip Types on Wrist and Club Head Kinematics during the Golf Swing: Benefits of a Local Co-ordinate System

Wrists movements have been identified as an important factor in the production of a successful golf swing, with their complex range of motion (ROM) influencing both club head velocity and orientation (Nesbit, 2005; PGA, 2008; Sprigings & Neal, 2000). They have also been identified as having the greatest angular velocities of all joints during the golf swing (Zheng, Barrentine, Fleisig, & Andrews, 2008) and are consistently reported as the primary injury site, particularly in the lead wrist (left in right-handed golfers), amongst high-level golfers (Barclay, West, Shoaib, Morrissey, & Langdown, 2011; McCarroll, Retting, & Shelbourne, 1990). For example, Barclay et al. reported within an international survey of 526 club and touring professionals a 66% prevalence of injury and within that sample a 44% incidence rate pertaining to the wrist. Therefore, it is important that sport practitioners are able to understand the nature of high-level golfers' lead and trail wrist kinematics during the golf swing. Consequently, this may offer a useful insight into the mechanisms of wrist injuries and a more detailed understanding of technique effectiveness.

To date, studies reporting three-dimensional wrist kinematics have been either forward dynamic (MacKenzie & Sprigings, 2009; Sprigings & Neal, 2000) or experimental (Cahalan, Cooney III, Tamai, & Chao, 1991; Fedorcik, Queen, Abbey, Moorman Iii, & Ruch, 2012; Zheng et al., 2008). However, little data exists on high- or elite-level golfers. Two studies that have reported findings from high-level participants are Zheng et al. (2008) and Fedorcik et al. (2012). Despite inclusion of high-level participants, data reported does not allow a complete analysis of wrist mechanics. Zheng et al. (2008) defined the wrist by the golf club shaft moving relative to the forearm, which is unlikely to provide a complete understanding about the three-dimensional movement patterns. This would also partly explain why previous data only exists in one or two axes of rotation; ulnar/radial deviation and flexion/extension (Fedorcik et al., 2012; Nesbit, 2005; Zheng et al., 2008). Further investigating the wrists' three-dimensional movement patterns could prove beneficial in understanding different strategies and their relationship to golf swing effectiveness.

Indeed, non-sporting studies have previously reported ROM in internal/external rotation about the wrist joint independently of forearm pronation/supination at the radioulnar joint. Gilmour, Richards and Redfern (2012) examined wrist kinematics during activities of daily living (ADL; e.g., opening/closing jars). Results from 9 healthy participants, which were reported and published as part of a conference proceeding, revealed a maximum mean ROM of 31.7°. Indeed, this finding is consistent with other studies using simulated ADL, where a mean radiometacarpal internal/external rotation (ROM) of 34.1° was reported (Gupta & Moosawi, 2005). Notably, it is acknowledged that wrist joint internal/external rotation is passively controlled (i.e., voluntary forearm rotation does not independently axially rotate the wrist joint) when performing ADL and external resistance is applied. In Gilmour et al.'s (2012) study, resistance was applied by the objects being manipulated; and Gupta and Moosawi (2005) actively forced rotation of the forearm by fixing the position of the phalanges. It is likely that the inertial moments caused by the club accelerations during the golf swing and/or the hands' orientation when gripping the handle, may also result in such rotation. Therefore, wrist joint internal/external rotation should be included in future three-dimensional analyses to allow for greater understanding.

Furthermore, existing research is limited by the amount of data provided during the golf swing. Previous studies have only reported data at specific events such as the top of the backswing and impact (e.g., Zheng et al., 2008). Despite this, studies have identified a common feature for the lead wrist amongst high-level golfers when compared to novices. Data indicate high-level golfers to be more radially deviated at the top of the backswing, coupled with a delayed transition to ulnar deviation during the downswing until impact

(Lindsay, Mantrop, & Vandervoort, 2008; Sharp, 2009; Sprigings & Neal, 2000). According to the Training Academy of The Professional Golfers' Association (PGA) of Great Britain and Ireland, these events represent the swing principle 'release,' which describes returning the clubface back in line with the target through the "impact position while freeing the power created in the backswing" (PGA, 2008, p. 48), which are important to both distance and accuracy. However, what appears to be lacking in the literature is a detailed three-dimensional analysis for both wrists during the entire golf swing and their relationship with club head measures at impact, and the effect of different grip types, often described by the address position. For example, a 'strong' grip presents the palm of the lead hand more on top of the handle and the trail hand more underneath, versus a 'weak' grip with the palm of the lead hand rotated anticlockwise around the handle and the trail hand more on top (see Figure 1). A weak grip (and vice versa for a strong grip) is described as such due to its apparent limiting influence on wrist 'action'/release, therefore reducing ball carry distance (Najar, 2010). Furthermore, golf coaching texts explain that the direction of clubface alignment at impact, relative to the intended target line, can be associated with grip type (PGA, 2010), which can be inferred by the extent of lead wrist flexion/extension at the top of the backswing. Addressing the latter, greater extension indicates a likely 'open' clubface and flexion a likely 'closed' clubface (Haney, 2012; PGA, 2008). Consequently, it is possible that some golfers may attempt adjustments to their grip to facilitate different shot shapes. If a complete three-dimensional analysis of the wrist joints were able to provide increased detail across the three planes of motion, it may be possible to assess for any exact changes in the wrist kinematics as a result of different starting grip techniques.

****Figure 1 here****

Therefore, the purpose of this study was twofold; firstly, to determine kinematics across both wrists during the golf swing when employing a three-dimensional analysis, and; secondly, to assess for any changes in club head characteristics at impact resulting from short-term (within session) grip modification under weak, neutral and strong grip conditions.

Method

Participants

Twelve right-handed male golfers ($M_{\text{age}} = 32 \pm 9.3$ years) were recruited for this study. All were PGA Professional golf coaches which meant that they did not have a handicap but would have required a maximum handicap of 4 prior to attaining professional status. Therefore, all golfers can be considered as highly skilled. Preceding data collection, participants were required to read an information sheet and provide informed consent. Ethical approval was gained from the University's Ethics Committee prior to data collection. Participant eligibility required no current or prior wrist injuries as assessed through self-report.

Procedures

Participants warmed-up using self-conducted exercises and practice tee shots from an artificial turf mat using their own driver and wearing golf shoes. Three blocks of eight full swing executions were completed, requiring a squash ball to be hit with participants' own driver towards a vertical target fixed on the laboratory wall approximately 15 m away. The first block required a natural and individually-preferred grip, therefore allowing the capture of participants most well-established movement patterns (Carson & Collins, 2016). Three participants had a naturally strong grip, seven a neutral grip and two a weak grip. Two repeated blocks then followed to satisfy the remaining grip conditions in a randomly assigned order. Grip manipulations were visually checked to ensure adequate understanding; all participants adhered to the task requirements at this stage by displaying the correct number of knuckles on each hand at the address position as shown in Figure 1. Accordingly, eight full swing executions were captured from each participant utilising a neutral, strong and weak grip technique.

Kinematic data were collected using 10 Oqus 700 cameras (Qualisys Medical AB, Sweden) at a sampling rate of 300 Hz. Qualisys Track Manager^{TM} (QTM, Version 2.11, Qualisys Medical Ltd., Sweden) was used to reconstruct the three-dimensional co-ordinates of 10 mm passive retro-reflective markers applied bilaterally to the following anatomical sites: medial and lateral humerus epicondyles, radial and ulnar styloid processes and 2nd and 5th metacarpal heads. Rigid clusters were positioned on the distal forearms and dorsum of the hands allowed segmental tracking in six degrees-of-freedom. Seven 6 mm markers were positioned on the four extremities of the clubface and three on the club head; the ball was also marked with retro-reflective tape. Four 10 mm passive retro-reflective markers were affixed onto the artificial turf mat in a cross formation to enable club head orientation and velocity to be calculated (Figure 2). A neutral static calibration trial was captured prior to testing with the participant adopting the anatomical position for 1 s, markers positioned at anatomical landmarks were subsequently removed prior to golf swing executions.

Figure 2 here

Data Processing

Raw kinematic data for a minimum of five trials from each condition per participant were exported into c3d file format and analysed using Visual 3D v5.01.25 software (C-Motion Inc., USA). Co-ordinate systems were assigned using joint centres defined by the medial and lateral markers on the proximal and distal aspects for each segment using a single frame of the static calibration trial (y-axis = anterior–posterior, x-axis = medial–lateral and z-

axis = proximal–distal). The radioulnar segments were defined proximally using the medial and lateral humerus epicondyles and distally using the radial and ulnar styloid processes. The hands were defined proximally using the radial and ulnar styloid processes and distally using the 2nd and 5th metacarpal heads. Wrist joint angles were calculated in all three axes of rotation of the distal segment relative to the local co-ordinate system (LCS) of the proximal segment, using an X (flexion/extension), Y (medial/lateral), Z (axial) Cardan sequence as previously employed within golf research to measure wrist mechanics (Joyce, Burnett, Cochrane, & Reyes, 2016; Sinclair, Currigan, Fewtrell, & Taylor, 2014), and is an equivalent Cardan sequence recommended by (Wu et al., 2005). Movement in extension, radial deviation and external rotation were defined as positive and flexion, ulnar deviation and internal rotation were defined as negative. The club head was defined proximally using the two superior markers on the clubface, with the marker closest to the shaft as the medial and the other as lateral; inferior clubface markers were used to define the clubface distally, again with the marker closest to the shaft as the medial and that furthest away as lateral. To ascertain the clubface angle at impact, the club head angle was referenced in the *z*-axis of the cross segment on the mat (positive values depicting a clubface pointing left of the ball-to-target line and negative values to the right of the ball-to-target line), in addition club head velocity was calculated at impact. Data were filtered using a low-pass Butterworth filter with a cut off frequency of 25 Hz.

Four events were identified and used to divide the swing into three phases, with the time between each event normalised to 101 points. “Onset” was defined when the club head linear speed crossed a threshold value of 0.0 m/s in the global *x*-axis on swing ascent. “Top” was defined when the club head linear speed reached its lowest negative value in the global *z*-axis prior to swing decent. “Impact” was defined immediately before the ball recorded a positive velocity. Finally, “Follow through” was defined when the left hand linear speed crossed a threshold of 0.0 m/s in the global *x*-axis following the impact event.

Statistical Analysis

Data were analysed using SPSS Statistics 23.0 (IBM Corporation, USA) software. Repeated measures ANOVAs were used to test for differences between wrist joint angles at the swing onset, top and impact events, maximum and minimum angles, ROM and clubface angle and velocity at impact. Main effects were assessed using the Greenhouse–Geisser correction when Mauchly’s sphericity test was violated and effect sizes were provided through the partial eta-squared (η_p^2) statistic. Post hoc pairwise comparisons were made using the Bonferroni test when appropriate. A P-value < 0.05 was considered as significant for all statistical tests.

Results

Golf swing wrist kinematics (means and standard deviations) for all grip types are shown in Table 1. The following details any significant findings.

Joint Angles at Identified Events

Onset. While it could not be predetermined based on previous empirical study exactly how the wrist joint would differ, it was important to test for at least some level of change to support the visual manipulation checks employed. For the left wrist, there were main effects with large effect sizes for grip type on flexion/extension, $P < 0.001$, $\eta_p^2 = 0.78$, and internal/external rotation, $P < 0.001$, $\eta_p^2 = 0.73$, angles, with significant differences evident in flexion/extension between neutral and weak ($P = 0.001$), neutral and strong ($P = 0.002$) and strong and weak ($P < 0.001$) grips and for internal/external rotation between neutral and weak ($P < 0.001$), neutral and strong ($P = 0.029$) and strong and weak ($P < 0.001$) grips. Similarly for the right wrist, main effects with large effect sizes for grip type were revealed in flexion/extension, $P < 0.001$, $\eta_p^2 = 0.78$ and internal rotation, $P < 0.001$, $\eta_p^2 =$

0.73, but also ulnar/radial deviation with a medium effect size, $P = 0.018$, $\eta_p^2 = 0.37$. Post hoc analyses revealed significant differences in flexion/extension between neutral and weak ($P = 0.003$), neutral and strong ($P < 0.001$), and strong and weak ($P < 0.001$) grips, in internal/external rotation between neutral and weak ($P = 0.001$) and strong and weak ($P < 0.001$) grips, with neutral and strong closely approaching significance ($P = 0.055$). No significant differences were found in right wrist ulnar/radial deviation although the differences between neutral and weak ($P = 0.088$) and weak and strong ($P = 0.061$) showed a trend towards significance.

Top. Data at the top of the swing reveal that onset differences were not always consistent. For the left wrist, there were significant main effects with a large effect size for grip type on flexion/extension, $P < 0.001$, $\eta_p^2 = 0.70$, and a medium effect size for internal/external rotation, $P = 0.008$, $\eta_p^2 = 0.35$, angles. Significant differences were shown in flexion/extension between neutral and strong ($P < 0.001$) and weak and strong ($P = 0.001$) grips, with neutral and weak grips only approaching significance ($P = 0.07$), and for internal/external rotation between strong and weak grips ($P = 0.036$). Right wrist kinematics showed main effects with a large effect size for grip type on flexion/extension, $P = 0.002$, $\eta_p^2 = 0.43$, and medium effect sizes for ulnar/radial deviation, $P = 0.022$, $\eta_p^2 = 0.37$, and internal rotation, $P = 0.03$, $\eta_p^2 = 0.27$. Post hoc tests revealed significant differences in flexion/extension between weak and strong ($P = 0.005$) grips and in ulnar/radial deviation between neutral and strong ($P = 0.02$) and weak and strong ($P = 0.045$) grips. No significant differences between grips were shown for internal/rotation angles.

Impact. There were significant main effects with large effect sizes for left wrist grip type on flexion/extension, $P = 0.002$, $\eta_p^2 = 0.57$, and internal/external rotation, $P = 0.003$, $\eta_p^2 = 0.49$, angles. Significant differences were shown in flexion/extension between neutral and strong ($P = 0.019$), neutral and weak ($P = 0.011$) and weak and strong ($P = 0.006$) grips, and for internal/external rotation between neutral and strong (P = 0.029) and strong and weak (P = 0.014) grips. Right wrist kinematics showed main effects with large effect sizes for grip type on flexion/extension, $F(2,22) = 8.98$, $P = 0.001$, $\eta_p^2 = 0.45$, ulnar/radial deviation, $P = 0.002$, $\eta_p^2 = 0.43$, and a medium effect size for internal rotation, $P = 0.004$, $\eta_p^2 = 0.39$. Post hoc analyses revealed significant differences between weak and strong grips in flexion/extension (P = 0.001), ulnar/radial deviation (P = 0.02) and internal/external rotation (P = 0.012) grips.

Minimum/Maximum Angles and Range of Motion

When analysing the entire golf swings from the onset to follow-through events, there was a significant main effect with large effect size of grip type on left wrist minimum flexion/extension, $P = 0.001$, $\eta_p^2 = 0.64$, and medium effect size for internal/external rotation, $P = 0.009$, $\eta_p^2 = 0.35$, angles. Post hoc tests showed significant differences within flexion/extension between neutral and strong ($P < 0.001$) and strong and weak (P = 0.002) grips and within internal/external rotation there was a trend towards significance between neutral and strong (P = 0.068) and strong and weak (P = 0.057) grips. There was a significant main effect with a medium effect size of grip type on right wrist minimum internal/external rotation angle, $P = 0.027$, $\eta_p^2 = 0.34$, but post hoc tests showed no significant differences between each of the grips. Right wrist minimum ulnar/radial deviation only tended towards significance, P = 0.051. There was a significant main effect with medium effect size of grip type on left wrist maximum flexion/extension, $P = 0.002$, $\eta_p^2 = 0.34$. Post hoc tests showed significant differences between neutral and strong (P = 0.012). There was a significant main effect with large effect size of grip type on right wrist maximum flexion/extension angle, $P = 0.007$, $\eta_p^2 = 0.43$. Right wrist maximum internal/external rotation approached significance, P = 0.064. Post hoc tests revealed significant differences for flexion/extension between strong and weak (P = 0.016), with neutral and strong grips almost reaching significance ($P = 0.05$). Despite these differences in minimum and maximum angles, overall ROM appeared to be relatively unaffected. There was only a significant main effect with medium effect size of grip type on left wrist flexion/extension ROM, $P = .045$, $\eta_p^2 = 0.29$. However, post hoc analyses revealed nonsignificant results.

Table 1 here

Club Kinematics at Impact

There was a significant main effect with a large effect size of grip type on clubface angle, $P = 0.001$, $\eta_p^2 = 0.47$. As expected, the neutral grip clubface angle was between the angles for strong and weak grips. Notably, all clubfaces were presented to the same side relative to the ball–target line, to the right (Table 2). Significant differences, however, were only found between neutral and weak ($P = 0.019$) and strong and weak ($P = 0.011$) grips. There was no significant main effect found for grip type on club head velocity, $P = 0.301$.

Table 2 here

Discussion

This study addressed methodological shortcomings of previous research into golf wrist mechanics by employing a three-dimensional analysis using anatomical LCSs. Furthermore, it compared several club head kinematics at impact resulting from purposeful, albeit acute, modifications to grip type within a sample of high-level golfers. Wrist movement was tri-planar in nature, indicating greater complexity than previously reported (Cahalan et al., 1991; Fedorcik et al., 2012; Zheng et al., 2008). While this method is not always appropriate for golf swing analyses (e.g., when analysing general timing), it is important to recognise that simplistic wrist analyses could ignore important movement patterns.

Regarding internal/external rotation, mean trail wrist ROM was similar to previous data (Gilmour et al., 2012; Gupta & Moosawi, 2005). Lead wrist mean ROM, however, was much higher. Internal rotation was similar between wrists, indicating that additional external rotation accounted for this difference. Considering the lead wrist's injury prevalence in high-level golfers, this subtle difference could be a contributing factor. Moreover, from the address position the lead wrist was closest to its maximum internal rotation angle, which is also likely to persist for the longest duration as the golfer sets up and prepares to execute the shot. Although currently speculative in nature, the tri-planar data certainly appears able to provide additional detail to begin exploring specific questions about golf swing technique and the underlying causes of performance. Similarly, researchers exploring the 'X-factor' principle have recently advocated the necessity for an anatomical LCS to gain a greater biomechanical meaning (Brown, Selbie, & Wallace, 2013). Other factors that might interact with this wrist movement to result in injury include the nature of club–ground contact and intensity of practice undertaken. At present, however, we await further investigations along these lines.

Looking beyond the novel internal/external rotation data, the nonsignificant differences in club head velocity suggests that any differential in observed shot distance between grip types may not be due to the transfer of energy to the club head. Instead, underpinning causes could reside with precision elements; for instance, clubface loft, angle in relation to the swing direction and, therefore, resultant ball trajectory. Further support for this can be inferred from the trail wrist flexion/extension ROM during the downswing—which is indicative of angular velocity and directly related to the amount of power applied (Sinclair et al., 2014)—showing very little/no change across the three grip conditions.

Differences between the tri-planar angles were however evident at impact. As such, it is possible that the type rather than the amount of movement needs further consideration when examining the golf swing ‘release’ principle (Najar, 2010). From these data and for this sample at least, simply changing the grip position does not appear beneficial to increasing club head velocity.

Top of the backswing data are also of interest. Specifically, the mean lead wrist was in extension irrespective of grip type and all club face angles were aligned to the right of the shot direction line (open) at impact. Notably, this is somewhat contrary to Haney’s (2012) explanation that the wrist angle at the top of the backswing, and subsequent impact orientation, could relate to grip. As a possible interpretation, these high-level golfers were able to resist the ‘likelihood’ of closing the clubface at impact with a strong grip, maintaining a relatively square position, whereas this was comparatively more challenging with a weak grip. This supports PGA’s (2010) suggestion that golfers tend closer towards a strong rather than weak grip. Indeed, most participants expressed a preference for either a neutral or strong grip during debriefs that followed the trials. It is perhaps, therefore, unsurprising that the strong grip could be more functionally adapted compared to the weak grip, due to increased familiarity and comfort in the executions.

Moreover, regarding individual differences, despite Table 1 showing strong–neutral–weak grips resulted in a fairly consistent and ordered ascending/descending sequence of angles for the variables, some showed no difference across conditions. Notably, upon inspection of individual data, no single participant entirely matched these ordered sequences from the group data. As such, this supports the rationale for individual technical analyses within coaching practice (Brown et al., 2011; Kostrubiec, Zanone, Fuchs, & Kelso, 2012). Undoubtedly, some movements will be similar across participants, therefore abiding by a general technical template. However, coaches should be cautious when constructing individualised mental models of performance not to fall into the ‘flaw of average’ heuristic trap (Rose, 2016) when assessing many swing variables. In short, the idea that a mental model of performance should target the average of skilled/elite players (e.g., Mann & Griffin, 1998), even if ‘windows’ around the mean are catered for (Rose, 2016), is inevitably suboptimal at best.

In addition to an improved understanding of mechanics by employing LCSs, there are also pragmatic advantages to be realised. Specifically, this arises when requiring longitudinal analyses, such as when diagnosing and monitoring technique during skill refinement (Carson & Collins, 2011). Using more commonly employed global co-ordinate systems in the lab and applied settings (e.g., a fixed camera positioned in the sagittal or coronal plane) cannot guarantee the exact relative positioning between the golfer and co-ordinate system axes between sessions. Consequently, intersession comparisons are less reliable and have greater planar cross-talk, with LCSs suffering fewer inconsistencies in measurement; data are less affected by variations across trials, days and environments.

Despite methods employed in this study, limitations must be recognised. Technique variations have been reported across different golf clubs (Egret, Vincent, Weber, Dujardin, & Chollet, 2003), especially when executing from the ground and not a tee. Further understanding would therefore derive from employing LCSs beyond the sole use of a driver. From a motor control perspective, issues of ecological validity are also noteworthy in that the laboratory environment is unrepresentative of golf course conditions (Pinder, Davids, Renshaw, & Araújo, 2011). It has been reported that changes in automaticity can occur following the removal of naturalistic features (Carson, Collins, & Richards, 2016), however we cannot say in this case whether kinematics were compromised in any way. Mobile technologies that permit motion capture on the golf course may be able to overcome this limitation in future investigations. Relatedly, when considering participants’ high skill status, two of the grip conditions were less familiar/comfortable and therefore reflect a short-term perturbation to technique which we would expect to be disruptive of control processes (Charlton & Starkey, 2011). Accordingly, we recommend caution in assuming that any differences truly represent well-established techniques. Future research may extend this novel methodology by testing between individuals with different preferable grip types and collecting valuable ball flight data to enhance our understanding of the relationship with performance outcomes. Finally, addressing the collection and processing of kinematic data, this study defined the hand as a rigid segment and was able to detect differences within that segment relative to the forearm, however a more detailed analysis of the structures within the hand maybe possible (Gupta & Moosawi, 2005), which may yield a greater understanding of the movement and injury risks during the golf swing. Additionally, while Joyce, Burnett, and Ball (2010) determined that different joint angles for the trunk resulted from different Cardan sequences, it is important to highlight that no research has yet investigated any such differences when assessing wrist motion.

Conclusion

This paper extends current knowledge relating to the lead and trail wrist mechanics during the golf swing, through use of anatomical LCSs. Specifically, its contribution can be seen in the identification of movement in internal/external rotation and the interpretation of data from a coaching perspective. It is hoped that the methods employed in this study can be used to inform future research into many aspects of skill, technique analysis and skill development, and provided a greater understanding of injury mechanisms and their prevention.

Disclosure Statement

There is no potential conflict of interest concerning this non-funded research.

References

Barclay, C., West, S., Shoaib, Q., Morrissey, D., & Langdown, B. (2011). Injuries patterns among professional golfers: An international survey. *British Journal of Sports Medicine, 45*, e1. doi:10.1136/bjsm.2010.081554.12

Brown, S. J., Nevill, A. M., Monk, S. A., Otto, S. R., Selbie, W. S., & Wallace, E. S. (2011). Determination of the swing technique characteristics and performance outcome relationship in golf driving for low handicap female golfers. *Journal of Sports Sciences, 29*, 1483–1491. doi:10.1080/02640414.2011.605161

Brown, S. J., Selbie, W. S., & Wallace, E. S. (2013). The X-Factor: An evaluation of common methods used to analyse major inter-segment kinematics during the golf swing. *Journal of Sports Sciences, 31*, 1156–1163. doi:10.1080/02640414.2013.775474

Cahalan, T. D., Cooney III, W. P., Tamai, K., & Chao, E. Y. S. (1991). Biomechanics of the golf swing in players with pathologic conditions of the forearm, wrist, and hand. *The American Journal of Sports Medicine, 19*, 288–293. doi:10.1177/036354659101900314

Carson, H. J., & Collins, D. (2011). Refining and regaining skills in fixation/diversification stage performers: The Five-A Model. *International Review of Sport and Exercise Psychology, 4*, 146–167. doi:10.1080/1750984x.2011.613682

Carson, H. J., & Collins, D. (2016). The fourth dimension: A motoric perspective on the anxiety–performance relationship. *International Review of Sport and Exercise Psychology, 9*, 1–21. doi:10.1080/1750984X.2015.1072231

Carson, H. J., Collins, D., & Richards, J. (2016). Initiating technical refinements in high-level golfers: Evidence for contradictory procedures. *European Journal of Sport Science, 16*, 473–482. doi:10.1080/17461391.2015.1092586

Charlton, S. G., & Starkey, N. J. (2011). Driving without awareness: The effects of practice and automaticity on attention and driving. *Transportation Research part F: Traffic Psychology and Behaviour, 14*, 456–471. doi:10.1016/j.trf.2011.04.010

Egret, C. I., Vincent, O., Weber, J., Dujardin, F. H., & Chollet, D. (2003). Analysis of 3D kinematics concerning three different clubs in golf swing. *International Journal of Sports Medicine, 24*, 465–470. doi:10.1055/s-2003-41175

Fedorcik, G. G., Queen, R. M., Abbey, A. N., Moorman Iii, C. T., & Ruch, D. S. (2012). Differences in wrist mechanics during the golf swing based on golf handicap. *Journal of Science and Medicine in Sport, 15*, 250–254. doi:10.1016/j.jsams.2011.10.006

Gilmour, A., Richards, J., & Redfern, D. R. M. (2012). Investigation of 3D planar wrist movements during activities of daily living. *Journal of Bone & Joint Surgery, British Volume, 94-B*, 65

Gupta, A., & Moosawi, N. A. (2005). How much can carpus rotate axially? An in vivo study. *Clinical Biomechanics, 20*, 172–176. doi:10.1016/j.clinbiomech.2004.09.014

Haney, H. (2012, 4 June). Check your left wrist. *Golf Digest.* Retrieved from http://www.golfdigest.com/story/hank-haney-left-wrist

Joyce, C., Burnett, A., & Ball, K. (2010). Methodological considerations for the 3D measurement of the X-factor and lower trunk movement in golf. *Sports Biomechanics, 9*, 206–221

Joyce, C., Burnett, A., Cochrane, J., & Reyes, A. (2016). A preliminary investigation of trunk and wrist kinematics when using drivers with different shaft properties. *Sports Biomechanics, 15*, 61–75. doi:10.1080/14763141.2015.1123764

Kostrubiec, V., Zanone, P.-G., Fuchs, A., & Kelso, J. A. S. (2012). Beyond the blank slate: Routes to learning new coordination patterns depend on the intrinsic dynamics of the learner—experimental evidence and theoretical model. *Frontiers in Human Neuroscience, 6*, 1–14. doi:10.3389/fnhum.2012.00222

Lindsay, D., Mantrop, S., & Vandervoort, A. (2008). A review of biomechanical differences between golfers of varied skill levels. *International Journal of Sports Science and Coaching, 3(Supplement 1)*, 187–197. doi:10.1260/174795408785024117

MacKenzie, S. J., & Sprigings, E. J. (2009). A three-dimensional forward dynamics model of the golf swing. *Sports Engineering, 11*, 165–175. doi:10.1007/s12283-009-0020-9

Mann, R., & Griffin, F. (1998). *Swing like a pro: The breakthrough scientific method of perfecting your golf swing*. New York: Broadway Books.

McCarroll, J. R., Retting, A. C., & Shelbourne, K. D. (1990). Injuries in the amateur golfer. *The Physician and Sports Medicine, 18*, 122-126

Najar, B. (2010, 11 November). Get a grip - The right grip for you. Retrieved from http://www.pga.com/golf-instruction/instruction-feature/fundamentals/get-grip-right-grip

Nesbit, S. M. (2005). A three dimensional kinematic and kinetic study of the golf swing. *Journal of Sports Science and Medicine, 4*, 499–519

PGA. (2008). *Study guide: Golf coaching I.* United Kingdom: The Professional Golfers' Association.

PGA. (2010). *Study guide: Introduction to golf coaching*. Sutton Coldfield: The Professional Golfers' Association of Great Britain and Ireland.

Pinder, R. A., Davids, K., Renshaw, I., & Araújo, D. (2011). Representative learning design and functionality of research and practice in sport. *Journal of Sport and Exercise Psychology, 33*, 146–155. doi:10.1123/jsep.33.1.146

Rose, T. (2016). *The end of average: How we succeed in a world that values sameness*. Canada: HarperCollins.

Sharp, R. S. (2009). On the mechanics of the golf swing. *Proceedings of The Royal Society A, 465*, 551-570. doi:10.1098/rspa.2008.0304

Sinclair, J., Currigan, G., Fewtrell, D. J., & Taylor, P. J. (2014). Biomechanical correlates of club-head velocity during the golf swing. *International Journal of Performance Analysis in Sport, 14*, 54–63

Sprigings, E. J., & Neal, R. J. (2000). An insight into the importance of wrist torque in driving the golfball: A simulation study. *Journal of Applied Biomechanics, 16*, 356–366. doi:10.1123/jab.16.4.356

Wu, G., van der Helm, F. C. T., Veeger, H. E. J., Makhsous, M., Van Roy, P., Anglin, C., . . . Buchholz, B. (2005). ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion—Part II: Shoulder, elbow, wrist and hand. *Journal of Biomechanics, 38*, 981–992. doi:10.1016/j.jbiomech.2004.05.042

Zheng, N., Barrentine, S. W., Fleisig, G. S., & Andrews, J. R. (2008). Kinematic analysis of swing in pro and amateur golfers. *International Journal of Sports Medicine, 29*, 487–493. doi:10.1055/s-2007-989229

Figures

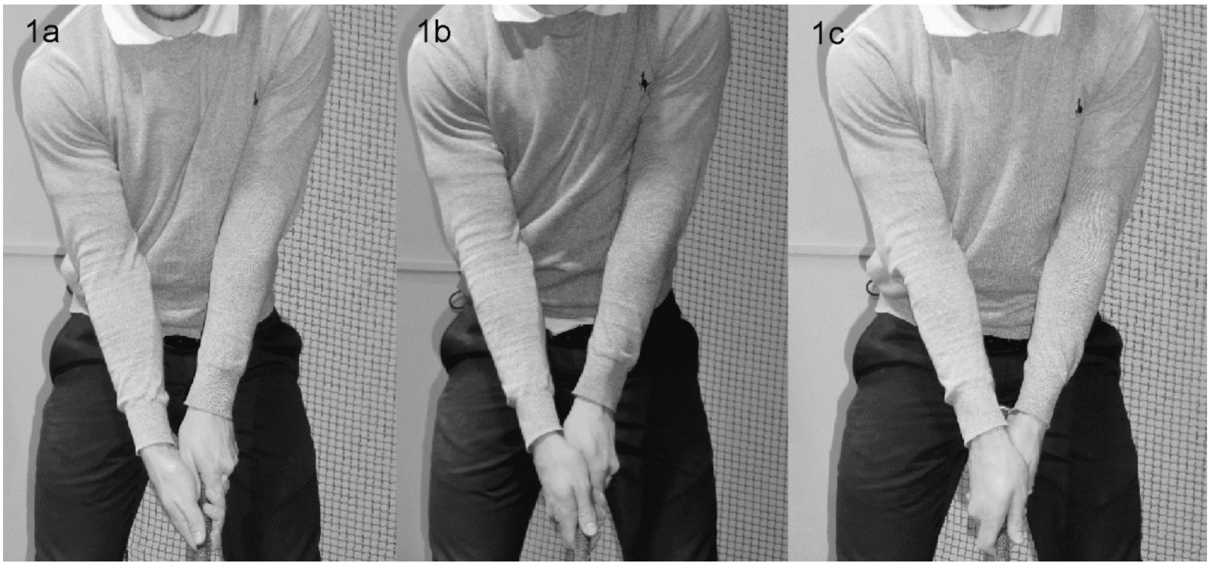

Figure 1. Different address grip positions viewed in the global coronal plane for a right-handed golfer. The strong grip (1a) is characterised by the lead hand being positioned on top of the handle with three knuckles shown to the golfer (first person perspective) and the trail hand wrapped underneath with one knuckle shown. The neutral grip (1b) presents the golfer with a view of two knuckles on each hand and the weak grip (1c) showing three knuckles on the trail hand and one on the lead.

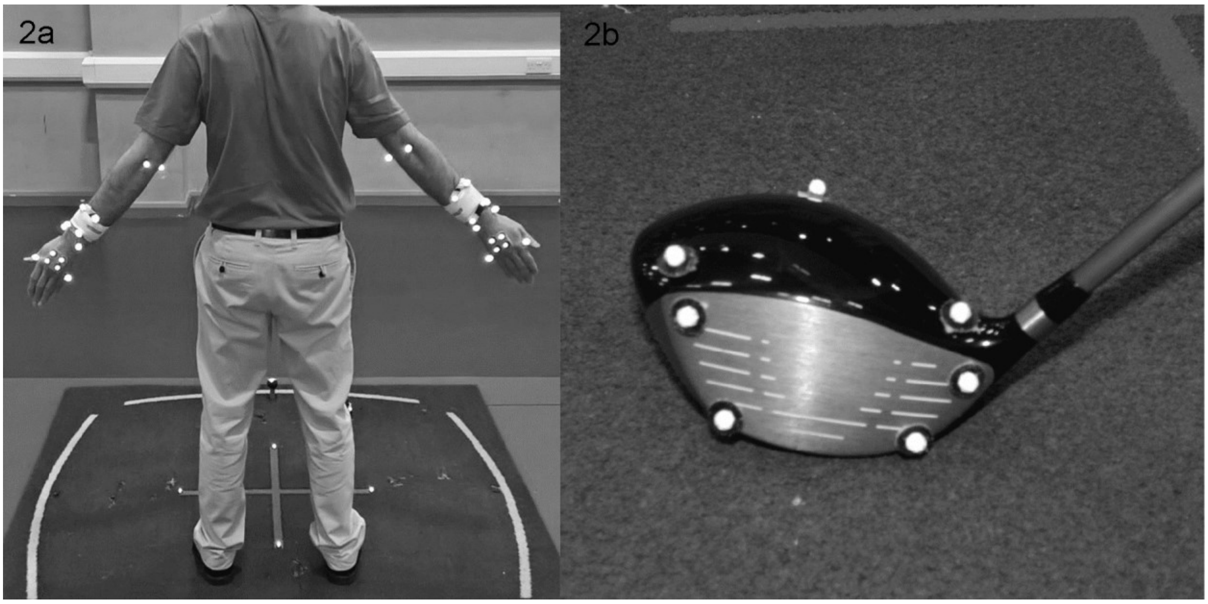

Figure 2. Anatomical and cluster marker placements on the forearm and hand segments, ball marker and floor markers (2a). Club head and clubface marker placements (2b).

Table 1. *Lead and Trail Wrist Kinematics*

	Left (Lead) Wrist			Right (Trail) Wrist		
	Strong	Neutral	Weak	Strong	Neutral	Weak
Swing Onset (°)						
Flexion/Extension	33.8 ± 10.0$^{*, **}$	29 ± 10.9$^{*, ***}$	22.2 ± 10.1$^{**, ***}$	−2.2 ± 4.7$^{**, ***}$	3.8 ± 5.4$^{*, **}$	11.4 ± 6.0$^{*, ***}$
Ulnar/Radial Deviation	−15.2 ± 11.7	−15.0 ± 11.1	−15.8 ± 10.7	−22.6 ± 8.8	−23.6 ± 8.9	−24.7 ± 8.8
Internal/External Rotation	−33.7 ± 6.1$^{**, ***}$	−29.9 ± 6.3$^{*, **}$	−24.6 ± 5.3$^{*, ***}$	−13.0 ± 7.4**	−16.9 ± 7.2*	−23.1 ± 8.1$^{*, **}$
Top (°)						
Flexion/Extension	14.4 ± 12.1$^{*, **}$	6.6 ± 11.8*	1.7 ± 10.6**	51.9 ± 10.2*	54.0 ± 11.3	57.6 ± 9.1*
Ulnar/Radial Deviation	26.3 ± 14.3	24.3 ± 12.6	22.4 ± 11.9	26.4 ± 6.2$^{*, **}$	24.8 ± 6.5*	21.5 ± 9.2**
Internal/External Rotation	−22.2 ± 10.3*	−23.6 ± 9.2	−24.7 ± 10.4*	−8.6 ± 10.0	−10.1 ± 10.0	−12.2 ± 10.0
Impact (°)						
Flexion/Extension	8.9 ± 10.5$^{*, ***}$	5.5 ± 12.5$^{*, **}$	3.0 ± 13.0$^{**, ***}$	19.9 ± 6.5*	21.3 ± 6.9	23.2 ± 6.4*
Ulnar/Radial Deviation	−24.2 ± 7.7	−24.6 ± 8.7	−25.3 ± 9.3	−22.7 ± 9.3*	−24.1 ± 9.9	−25.7 ± 11.0*
Internal/External Rotation	−24.2 ± 7.0$^{*, **}$	−21.4 ± 7.1*	−19.0 ± 8.5**	−16.2 ± 8.9*	−18.0 ± 9.1	−21.1 ± 6.8*
ROM (°)						
Flexion/Extension	59.76 ± 14.3	61.65 ± 13.2	64.11 ± 12.9	76.85 ± 11.2	77.85 ± 10.2	78.56 ± 9.9
Ulnar/Radial Deviation	63.82 ± 9.9	63.36 ± 10.0	63.27 ± 11.5	72.73 ± 7.5	73.27 ± 8.0	72.97 ± 7.7
Internal/External Rotation	45.77 ± 9.6	45.20 ± 7.4	44.5 ± 8.7	32.95 ± 11.7	32.01 ± 11.3	33.53 ± 12.2

Minimum Angle (°)						
Flexion/Extension	−3.58 ± 9.8$^{*, **}$	−8.24 ± 9.3*	−11.56 ± 7.4**	−18.19 ± 9.3	−17.43 ± 9.4	−15.33 ± 9.9
Ulnar/Radial Deviation	−29.03 ± 8.2	−28.70 ± 8.0	−28.80 ± 8.1	−38.0 ± 7.7	−38.70 ± 7.3	−39.01 ± 7.5
Internal/External Rotation	−39.02 ± 8.8	−37.21 ± 8.6	−36.47 ± 8.7	−30.57 ± 6.1	−30.58 ± 6.0	−33.78 ± 5.5
Maximum Angle (°)						
Flexion/Extension	56.18 ± 10.2*	53.40 ± 10.4*	52.60 ± 11.2	58.66 ± 11.2*	60.42 ± 10.7	63.22 ± 9.6*
Ulnar/Radial Deviation	34.80 ± 12.8	34.66 ± 12.1	34.48 ± 12.8	34.74 ± 7.0	34.57 ± 8.0	33.96 ± 7.5
Internal/External Rotation	6.76 ± 6.9	7.98 ± 6.7	8.03 ± 8.3	2.38 ± 10.3	1.42 ± 10.9	−0.24 ± 10.9

Table 2. *Club Head Kinematics at Impact*

	Grip Type		
	Strong	Neutral	Weak
Angle (°)	−1.51 ± 4.7**	−2.57 ± 4.5*	−6.36 ± 6.9$^{*, **}$
Velocity (m/s)	38.2 ± 3.6	38.6 ± 4.0	38.0 ± 3.4

*, ** indicates significant differences, $P < 0.05$, of pairwise comparisons